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BY

A. V. BLEININGER AND G. H. BROWN.

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THE BEHAVIOR OF FIRE BRICKS UNDER LOAD CONDITIONS AT A TEMPERATURE OF 1300°C.¹

BY

A. V. BLEININGER AND G. H. BROWN, Pittsburg, Pa.

PRELIMINARY STATEMENT.

In this paper the writers are dealing with the definite problem of the load-carrying ability of fire bricks, and they make no claim that the test described by them will discriminate as to the general usefulness or value of a refractory. A material which might make a poor showing in this test might be useful for many purposes, where the strength at the temperature employed is a minor consideration.

In the study of the effect of heat upon clays and clay mixtures, it is necessary to keep in mind the fact that the phenomena of fusion are by no means confined to temperatures close to the so-called melting or softening point, but manifest themselves already at heats hundreds of degrees below the stage of viscous fusion. In fact, we can say that clays and clay mixtures do not possess a definite melting point. In testing a specimen of fire clay or of fire brick, fusion is said to have taken place when the test pyramid or specimen has softened sufficiently so that its edges are rounded, and it has bent over in the well known manner. As a matter of fact, for all practical purposes, a fire brick would have been completely distorted, and would have shown all signs of fusion at considerably lower temperatures owing to its inability to support its own weight. It is simply due to the viscosity of the mass and to the fact that no load is imposed upon it, that it does

¹ By permission of the Director, U. S. Geological Survey.

not show the distortion coincident with softening. It is evident, therefore, that the determination of the so-called melting point of a clay or fire brick, though useful in differentiating between low and high grade materials, does not offer a reliable means of expressing the entire refractory behavior.

Thus Purdy¹ found the fusion points of evidently inferior clays to be quite high. He reports, for instance, a clay of the formula $5.1 \text{ SiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot 0.046 \text{ Fe}_2\text{O}_3 \cdot 0.09 \text{ TiO}_2$ to have a "fusion" point corresponding to cone 32. Similar results have been obtained in the Survey laboratory at Pittsburg.

The function of viscosity in extending the softening period is clearly recognized by all who have worked with silicates.

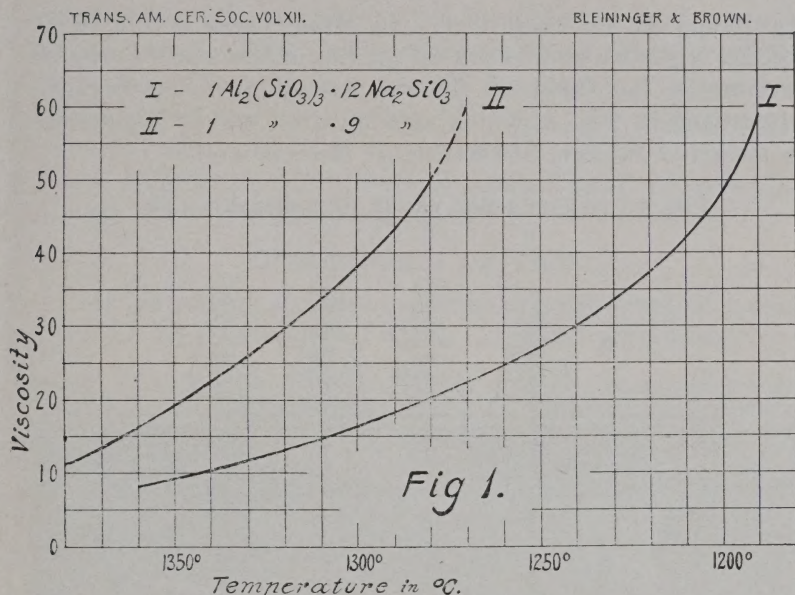
Thus Day and Allen,² in their investigations, bring out this point very clearly. Doelter, and his students in fact, have endeavored to determine the viscosity of different silicates at various temperatures. Vogt, likewise, has sought to correlate the viscosity of fused magma with the sequence and velocity of crystallization.

Greiner³ determined, by means of a specially constructed apparatus, the viscosity of mixtures of Na_2SiO_3 with various other silicates at different temperatures. Thus, in a mixture of Na_2O , SiO_2 and Al_2O_3 he found that the viscosity was greatly increased by the addition of as small an amount as 2.5 per cent of Al_2O_3 . This is shown graphically in Fig. 1, where the abscissæ represent the temperatures and the ordinates the relative viscosity. Curve I corresponds to the formula $\text{Al}_2\text{O}_3 \cdot 12 \text{ Na}_2\text{O} \cdot 15 \text{ SiO}_2$ and Curve II to $\text{Al}_2\text{O}_3 \cdot 9 \text{ Na}_2\text{O} \cdot 12 \text{ SiO}_2$. If alumina thus increases the viscosity of Na_2SiO_3 , which is one of the most mobile silicates, it is evident that the internal

¹ Ill. State Geol. Survey, Bull. No. 4, p. 133.

² The Isomorphism and Thermal Properties of the Feldspar, Carnegie Inst., 1905.

³ Inang. Dissertation, Jena. 1907, p. 17.



friction of highly aluminous combinations must be very high indeed.

On the other hand, the criticism raised as regards melting point determinations, does not apply to silicious mixtures containing a base-like lime. In testing silica brick it has been found that the melting point is well defined, as we should expect from our knowledge of the calcium silicates. Such a brick will stand up well in the fire, even under heavy loads, without deformation, at temperatures at a safe interval below its melting point. There is practically no flow until the melting point has been reached, when it will suddenly fuse to a liquid of low viscosity. This is probably the reason why silica brick are now being employed in many places where load conditions are an important factor, as in gas benches, etc.

In order to overcome the viscosity effect of the fused mass it evidently seems desirable to bring about conditions which will neutralize it. For this reason some investigators have found it advisable to apply a slight load to the

specimens to be examined. In some cases a platinum weight is used which is placed on top of the small cylinder or cone in the furnace. Howe¹ has suggested a furnace illustrated in Fig. 2, which arrangement makes it possible to measure the rate of settling or flow as well.

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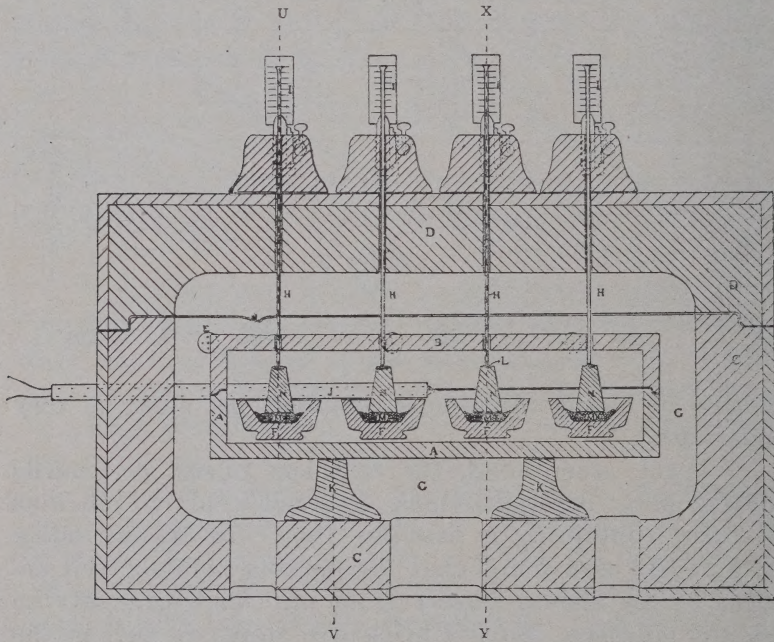


Fig 2.

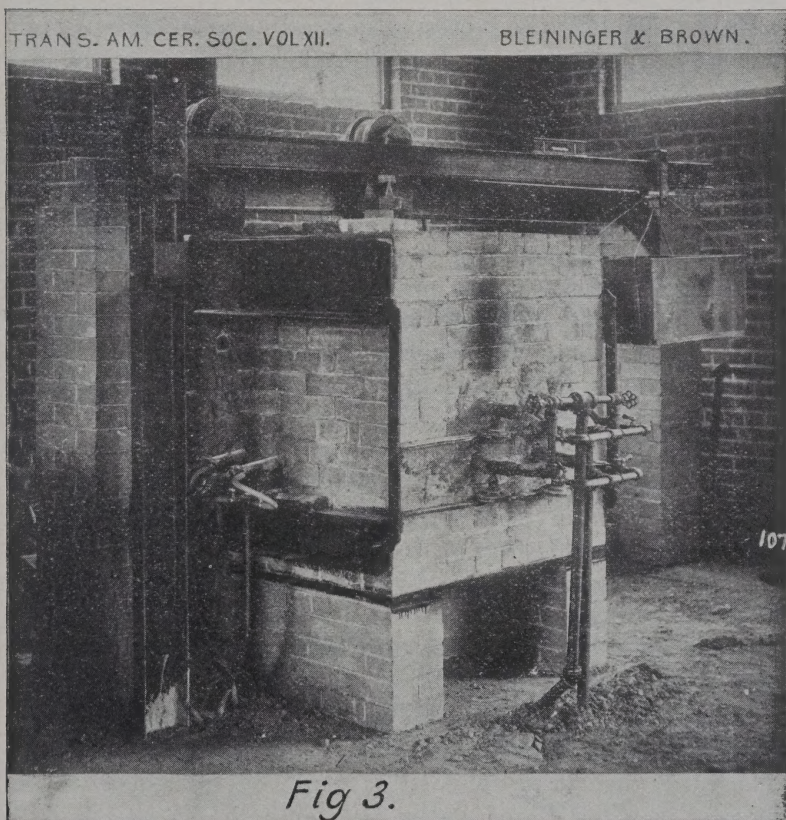
For the solution of the problem at hand, viz., the resistance of fire bricks to load conditions, it was decided not to approach the softening temperature proper, at which the whole mass becomes a viscous liquid, but to restrict our work to average furnace temperatures at which only the more fusible silicates are softening. In the average fire brick, containing from 80 to 85% of flint clay and

¹ Metallurgical Laboratory Notes, p. 50.

20 to 15% plastic bond clay, it is obviously the character of the latter which would determine the behavior of the brick from this standpoint, since the flint clay within this region shows no fusing action whatever. In order to bring out the point sought, it was evidently necessary to apply loads somewhat greater than those used in practice, though it was realized that it must not be excessive.

DESCRIPTION OF TEST.

In preparing for this investigation the work of Lemon Parker² was consulted, whose interesting results were



² Transactions American Ceram. Soc., Vol. 7, Part II.

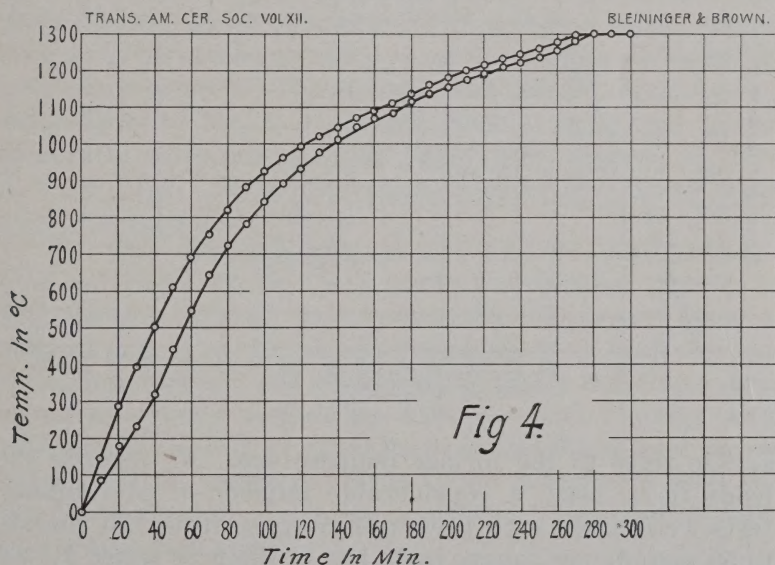
found very suggestive, though in his work only small specimens were used.

Since it was thought advisable to use full sized bricks, a furnace was constructed as illustrated in Fig. 3, with an interior space of 20"x 20"x 21", heated by means of eight Fletcher burners, which were supplied with natural gas and compressed air. The combustion gases escape through holes along the back side of the furnace, which consists of a movable door made from a heavy wrought iron frame lined with fire bricks. This frame is hung from two rollers running on an overhead track, so that it can be easily moved. The brick to be tested is firmly placed on end upon a heavy fire clay block about 9 inches from the door, and made to set plumb by means of fire clay mortar. The half of a chrome brick is then placed upon the test specimen and on top of it a long cylinder, made from high grade fire clay which extends through a hole in the arch of the furnace. The load is then applied upon a cast iron knife-edge plate by means of a steel I-beam 9 ft. long, with a distance of three feet between the pin taking the up-thrust and the fulcrum, and six feet between the latter and the point of load application. The weight of the beam is 155 pounds. The weight applied consists of a wooden box containing the necessary amount of iron shot. The beam was first calibrated by means of a platform scale. The pin at the one end of the beam passes through a cast-iron block sliding in a channel iron provided with a slit and a heavy fastening bolt. On top of the block two bolts are arranged so that it can be lowered by loosening the fastening bolt and tightening up the top nuts. In this manner the I-beam may be kept level throughout the test, thus avoiding any side strains upon the brick.

Through an opening in the door a thermo couple is inserted, which is placed as close to the brick as possible. The junctions of the element are placed in test-tubes immersed in a beaker of water, the temperature of which is read regularly.

Before beginning the regular tests it was, of course, necessary to determine the best working temperatures and pressures for the purpose in view, and in this the experience of Mr. Parker, as given in the article cited above, was used as a guide.

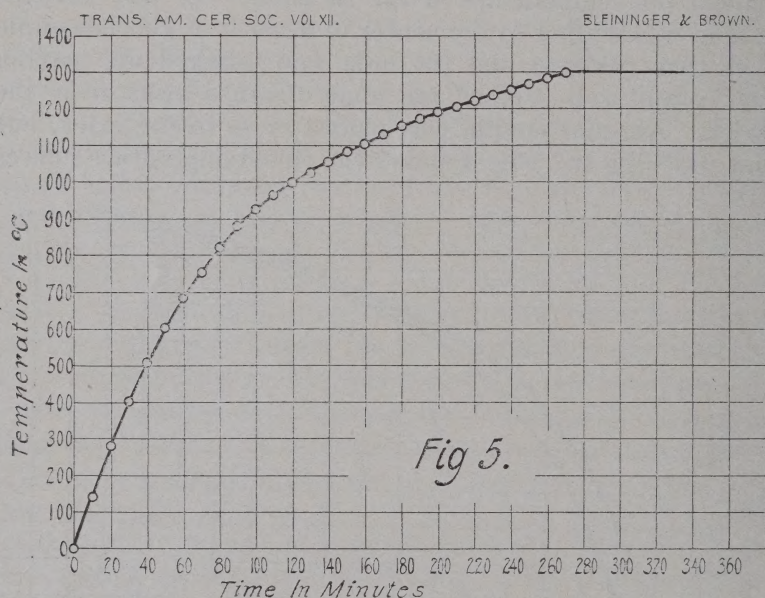
The first point it was necessary to determine was the rate at which a fire brick could be heated up, and the time required until the interior of the test specimen had assumed the temperature of the furnace. For this purpose a hole was drilled to the center of a brick. A thermocouple was then inserted and the hole well plugged up, leaving the couple well covered for some distance away from the brick. Another couple was placed close to the brick, but not touching it. Fig. 4 shows the time-temperature curves



resulting from this test, which illustrate that after 285 minutes, at the rate of heating followed, the inside temperature was the same as that on the outside. Since it was necessary to conduct the test with reasonable rapidity, owing to the limited hours during which power was available,

the time-temperature curve shown in Fig. 5 was finally adopted.

The temperature to which the brick was to be brought and held for one hour in one series of tests was taken to be 1300°C ., based on the consideration that the more easily fusible combinations of silicate mixtures vitrify and soften within this heat region. In the second series the temperature was raised to 1350°C . The tests described in this



article refer to the former temperature. As regards the loads to be used, a considerable number of preliminary tests were made with pressures ranging from 125 pounds to 50 pounds per square inch, but in the first series a load of 75 pounds per square inch was employed, and in the second, 50 pounds. The present results refer to the 75 pound load condition maintained for one hour at 1300°C .

In addition to the load tests, the following determinations were made:

1. Crushing strength of the bricks on end in the cold condition.
2. Chemical analysis.
3. Softening temperature.
4. Porosity.
5. True specific gravity.
6. Decrease in water absorption on re-burning to cone 12.

1. The crushing strength of the bricks, placed in the machine endwise, was carried on in the usual way, pains having been taken to imbed the specimen in plaster.

2. For the purpose of the chemical analysis, a sample sufficiently large was obtained by breaking up two half bricks and crushing them to pass the 100 mesh sieve. The disintegrated sample was allowed to flow in a small stream over a powerful magnet until all of the particles of metallic iron were removed. The analysis was carried on under the supervision of Mr. P. H. Bates, chemist in charge of the structural materials chemical laboratory, assisted by Mr. A. J. Phillips. The methods advocated by Hillebrand were used throughout this work.

3. The softening temperature was obtained by chipping off specimens from the bricks and placing them in a Fletcher gas furnace, using preheated compressed air and natural gas. For the higher temperatures a small carbon resistance furnace was employed, in which the muffle consisted of a body containing 85% calcined alumina and 15% of kaolin, Fig. 6. This furnace was found very satisfactory for the purpose. Seger-Orton cones were used for the determination of the temperatures. The results were checked in each case.

4. The porosity was determined by obtaining the weight of a dry piece of the brick, the weight of the same specimen saturated with water by boiling in vacuo and the suspended weight. The results checked practically with the porosity, calculated from the true and apparent specific gravities.

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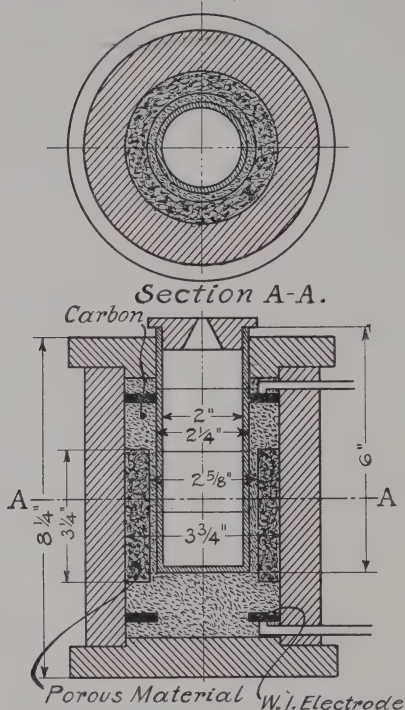


Fig 6.

5. The true specific gravity was obtained from 50 gram samples of the pulverized bricks, under the customary precautions as to the removal of air by boiling in vacuo and making corrections for the final temperature of the water.

6. The original weighed bricks in this case were tested for water absorption by placing them flatwise in a covered tank, containing $1\frac{1}{2}$ inch of water, for 48 hours. After weighing they were dried and burnt in a down-draft test kiln to cone 12. They were then again immersed as before, and the water absorption determined.

In this work 26 brands of fire bricks were tested, and each manufacturer was requested to furnish 20 bricks.

The writers desire to take this opportunity for thanking the various companies for their co-operation, and the interest taken in this work.

RESULTS OF TESTS.

In Table I the chemical analyses, as well as the calculated empirical formula, are compiled.

The results of the physical tests are arranged in Table II, and the data referring to the load test, as has been said above, apply to the load of 75 pounds per square inch and the temperature of 1300°C.

TABLE I.
Chemical Analyses.

No.	% Silica	Alumina	Titanium Oxide	Beric Oxide	Lime	Magnesia	Potash	Soda	EQUIVALENTS							Na ₂ O	RO*
									SiO ₂	Al ₂ O ₃	TiO ₂	FeO	CaO	MgO	K ₂ O		
1.....	81.60	14.55	0.49	1.15	0.37	0.27	1.08	0.67	9.180	1.0	0.041	0.098	0.045	0.046	0.079	0.074	0.342
2.....	79.20	17.42	0.49	1.19	0.21	0.38	.91	0.37	7.732	1.0	0.036	0.087	0.022	0.056	0.057	0.035	0.257
3.....	77.02	18.35	0.52	1.32	0.48	0.28	1.49	0.62	7.140	1.0	0.036	0.092	0.037	0.038	0.088	0.060	0.315
4.....	54.58	37.35	1.57	4.10	0.54	0.53	1.02	0.42	2.485	1.0	0.054	0.140	0.026	0.036	0.030	0.019	0.251
5.....	54.70	39.72	1.86	1.32	0.29	0.52	1.07	0.64	2.343	1.0	0.057	0.042	0.013	0.033	0.043	0.038	0.169
6.....	54.69	38.86	1.92	1.41	0.35	0.52	1.57	0.91	2.386	1.0	0.064	0.046	0.016	0.034	0.044	0.038	0.178
7.....	54.25	38.90	1.92	1.83	0.41	0.78	1.26	0.78	2.365	1.0	0.064	0.060	0.019	0.051	0.035	0.033	0.198
8.....	52.30	41.52	2.46	1.28	1.02	0.45	0.94	0.28	2.142	1.0	0.075	0.039	0.045	0.028	0.025	0.011	0.148
9.....	63.89	29.28	2.40	2.05	0.27	0.29	1.71	0.40	3.710	1.0	0.105	0.089	0.017	0.025	0.063	0.022	0.216
10.....	60.37	34.83	2.05	1.37	0.39	0.31	0.67	0.20	2.947	1.0	0.075	0.050	0.020	0.023	0.021	0.009	0.123
11.....	61.35	32.65	1.98	2.15	0.46	0.50	0.86	0.17	3.196	1.0	0.077	0.064	0.026	0.039	0.029	0.009	0.167
12.....	55.66	36.52	2.40	2.59	0.49	0.61	1.73	0.18	2.591	1.0	0.085	0.090	0.024	0.043	0.051	0.008	0.216
13.....	68.73	25.12	1.32	2.26	0.36	0.49	1.62	0.25	4.651	1.0	0.067	0.115	0.026	0.050	0.070	0.002	0.263
14.....	60.77	32.63	1.94	2.89	1.12	0.26	0.46	0.26	3.168	1.0	0.076	0.113	0.063	0.020	0.015	0.013	0.224
15.....	56.55	36.64	1.90	2.84	1.34	0.22	0.43	0.32	2.634	1.0	0.066	0.099	0.067	0.015	0.013	0.014	0.208
16.....	50.76	44.24	2.03	1.45	0.33	0.29	0.60	0.34	1.952	1.0	0.059	0.042	0.014	0.017	0.015	0.013	0.101
17.....	62.14	32.29	1.42	2.65	0.71	0.50	0.38	0.13	3.294	1.0	0.051	0.104	0.040	0.039	0.013	0.007	0.203
18.....	62.74	31.80	1.53	2.45	0.75	0.56	0.18	0.15	3.354	1.0	0.061	0.100	0.043	0.037	0.006	0.009	0.195
19.....	35.46	57.98	2.70	1.40	0.29	0.29	1.30	0.75	1.040	1.0	0.059	0.031	0.009	0.013	0.014	0.021	0.088
20.....	52.89	43.41	2.12	0.90	0.16	0.13	0.27	0.36	2.072	1.0	0.062	0.003	0.004	0.076	0.007	0.016	0.106
21.....	65.41	29.50	1.38	2.75	0.45	0.25	0.34	0.10	3.770	1.0	0.060	0.119	0.003	0.022	0.013	0.006	0.163
22.....	66.53	28.66	1.36	2.35	0.58	0.42	0.19	0.28	3.930	1.0	0.060	0.104	0.037	0.037	0.007	0.016	0.201
23.....	66.28	29.12	1.79	1.55	0.59	0.23	0.30	0.27	3.871	1.0	0.078	0.069	0.037	0.020	0.011	0.015	0.152
24.....	77.82	19.00	1.65	1.01	0.22	0.06	0.28	0.10	6.953	1.0	0.111	0.068	0.021	0.008	0.016	0.009	0.122
25.....	56.62	39.19	1.69	1.95	0.36	0.08	0.19	0.18	2.458	1.0	0.055	0.063	0.019	0.005	0.005	0.008	0.100
26.....	54.51	40.42	2.46	1.90	0.35	0.17	0.20	0.16	2.293	1.0	0.028	0.060	0.016	0.011	0.005	0.007	0.099

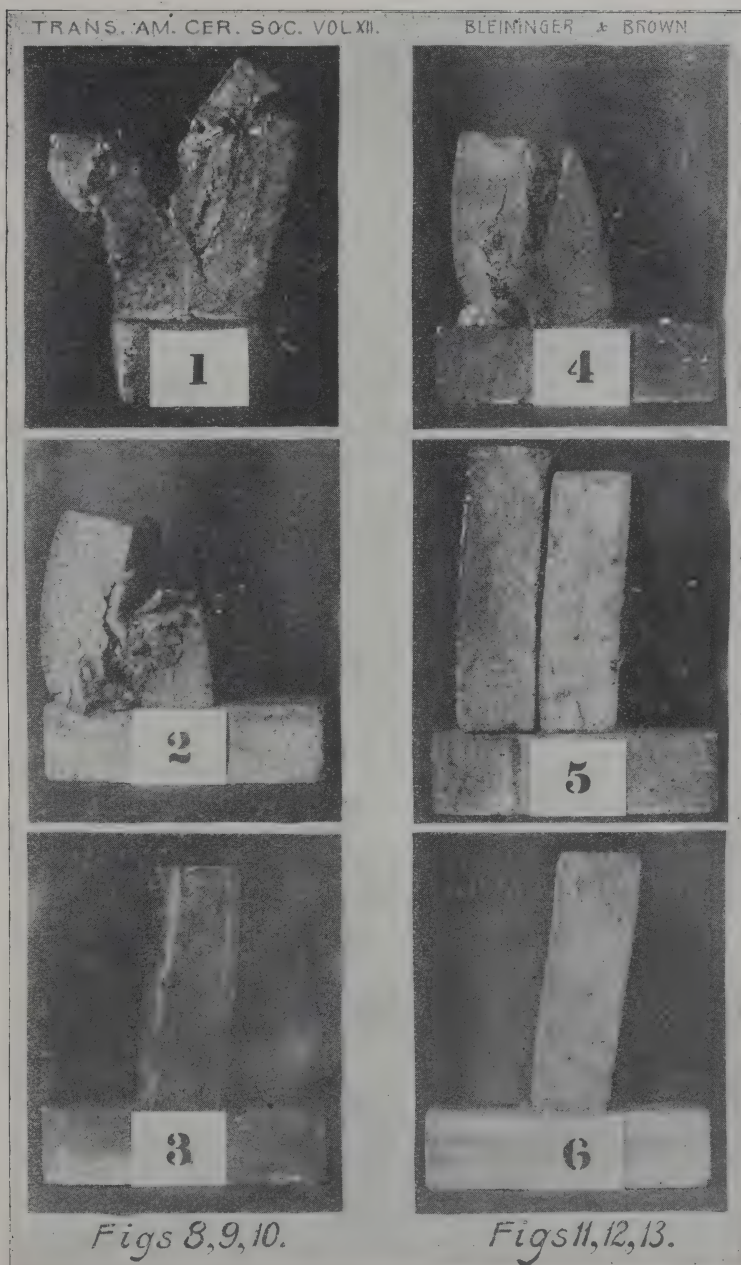
*RO = K₂O + Na₂O + CaO × MgO + FeO

TABLE II.
Physical Tests.

No	Crushing strength, cold, lbs. per sq. in.	% Porosity	True Specific Gravity	Softening Temp. in Cones	Height of brick before load test, inches	Height of brick in inches after load test	Temp. at which deflection started, °C	Compression of brick in inches	% Water absorption of brick in terms of dry wt.	% Water absorption of brick in terms of dry wt. after reburn- ing to cone 12	Decrease in water reburning
1	1464	30.2	2.591	28	9	Crushed	1213	Crushed	12.89	12.00	0.89
2	1289	30.1	2.592	28	9	Crushed	1247	Crushed	12.90	10.12	2.78
3	989	32.4	2.656	23	8%	Distorted	1210	Badly Distorted	11.47	5.53	5.94
4	495	25.8	2.797	29	9	Crushed	1180	Crushed	9.97	7.55	2.42
5	1160	23.0	2.670	31½	8%	8½	1191	Crushed	10.31	7.53	2.78
6	931	22.9	2.632	31	9	8¼	1213	¾	8.75	7.22	1.53
7	674	20.7	2.671	31	9	7¾	1215	1¼	7.35	4.46	2.89
8	1082	17.1	2.640	34	8¾	8%	1082	%	13.18	8.57	4.61
9	612	29.4	2.651	29½	8¾	Crushed	1191	Crushed	13.08	9.60	3.48
10	946	27.5	2.662	33	8¾	8½	1179	%	11.17	8.36	2.81
11	480	25.1	2.669	28	9	7½	1133	1½	9.13	4.13	5.00
12	2614	24.5	2.640	26	9	Crushed	1142	Crushed	10.49	5.00	5.49
13	843	22.5	2.658	28½	8¾	Crushed	1130	Crushed	8.55	6.55	2.00
14	2226	25.5	2.707	31½	8%	8 5-16	1211	9-16	7.39	8.34	1.49
15	1638	23.1	2.672	32	8¾	7¾	1234	1	10.72	8.24	2.38
16	971	24.3	2.678	34	9	8	1205	1	8.82	7.23	1.59
17	2578	23.9	2.629	31	8¾	8 1-16	1233	13-16			
18	955	21.0	2.638	33	8¾	8 3-16	1274	13-16	15.56	12.51	3.05
19	2071	33.3	2.991	33	9½	8½	1235	5%	13.98	10.84	3.14
20	1005	26.8	2.694	31	8¾	8½	1213	¼	8.59	7.68	0.91
21	3174	22.2	2.642	32	8¾	8 9-16	1231	5-16	11.15	10.22	0.93
22	2191	26.8	2.662	31	8¾	8½	1234	5%	9.53	8.20	1.33
23	4234	23.9	2.649	30	8¾	8 5-16	1264	9-16	12.39	10.42	1.97
24	2551	27.5	2.600	29	9	8¾	0	1½	12.62	8.76	3.86
25	1241	26.3	2.695	31½	9	8¾	1291	¼	11.90	6.42	5.48
26	1138	22.3	2.685	31	8¾	7¾	1207	1¼			

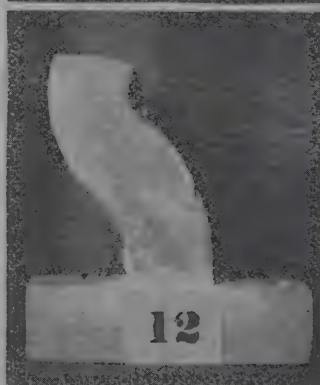
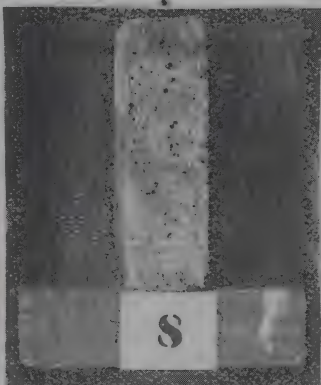
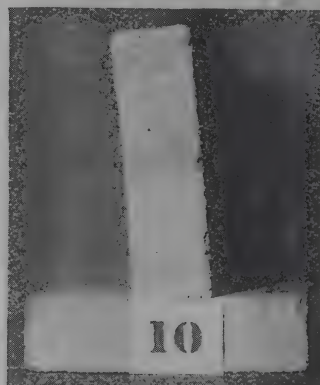
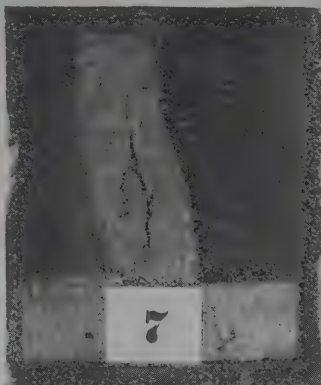


Fig. 7 represents the fracture resulting from the crushing test in the cold. The break is normal, and agrees with the theoretical considerations. In the following plates the photographs of the fire bricks, after having been subjected to the load test, are reproduced.



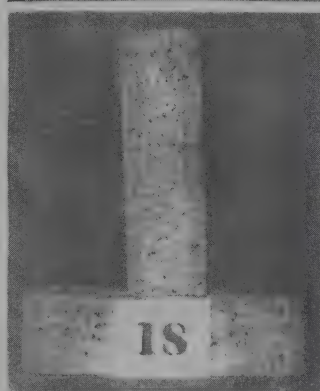
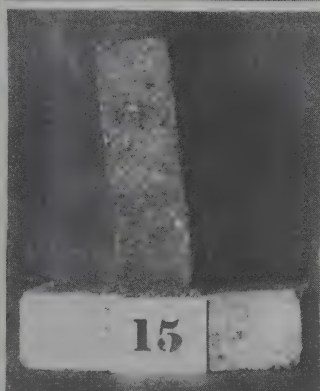
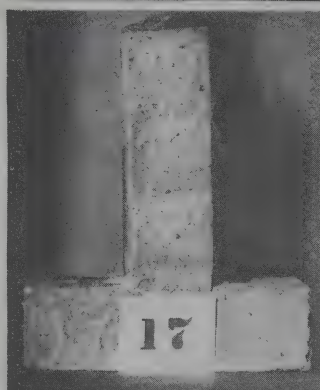
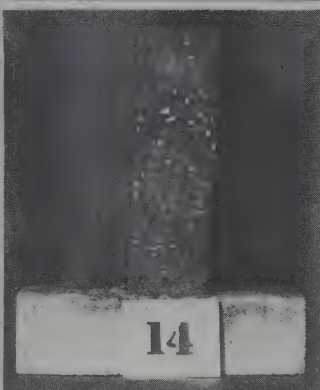
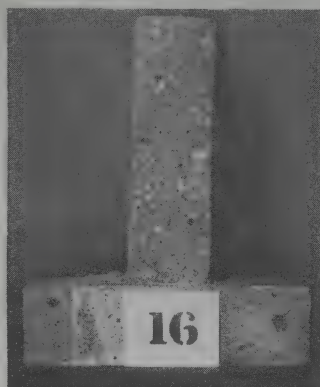
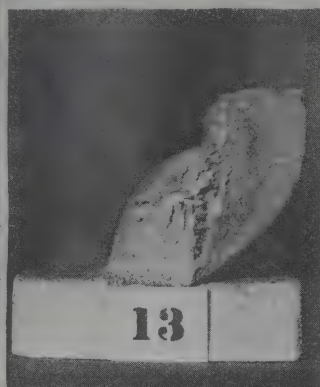
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*Figs 14, 15, 16.**Figs 17, 18, 19.*

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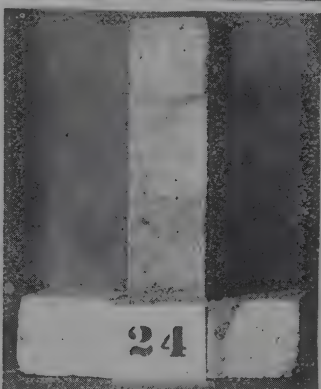
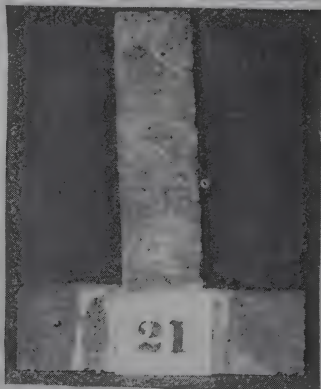
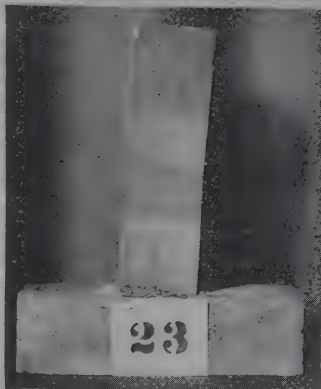
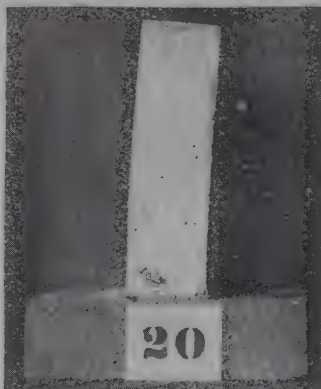
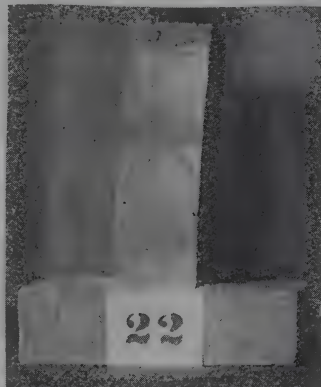
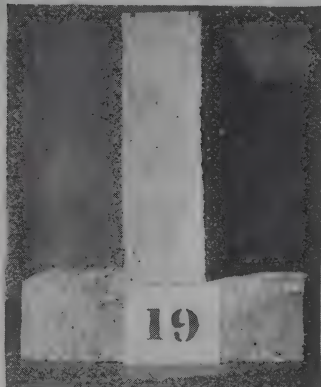


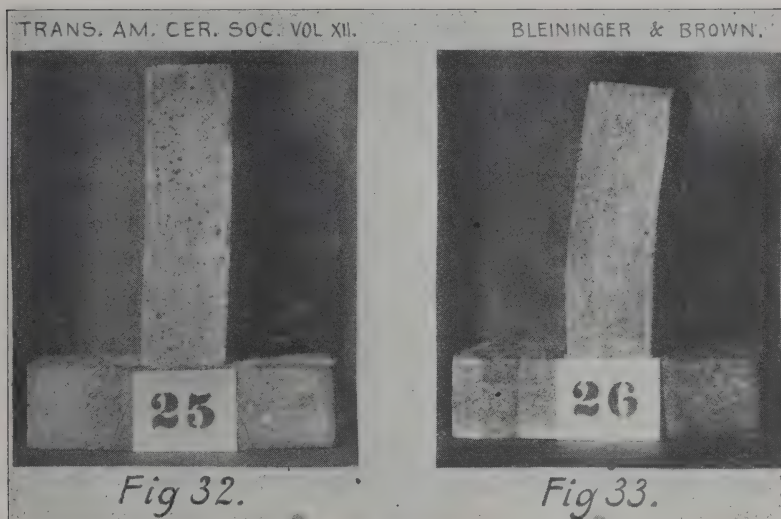
Figs 20, 21, 22.

Figs 23, 24, 25.

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*Figs 26, 27, 28.**Figs 29, 30, 31.*



From these it appears that in the cases where the bricks were badly distorted and crushed, in each case a certain degree of softening took place, as is clearly indicated by the curved surfaces. It is evident that these bricks attained a viscous condition in which they were not able to carry the load imposed upon them, though the latter is small compared with the crushing strength at the atmospheric temperature. In no case is the fracture as sharp as is shown in Fig. 7, but invariably clear evidence of flow is produced.

In carrying on the load test as the temperature rises, the beam is first raised, due to the expansion of the furnace bottom and the brick, a quiescent stage is then reached after which, from 1130 to 1290°, a well defined deflection begins, caused by the contraction of the brick. In some bricks this deflection continues at a very slow rate, or reaches a condition of equilibrium some time after the temperature has been raised to 1300°. This kind does not fail under the conditions of the test, and the later deflection starts the more apt is the brick to stand up. The materials failing under this test show a more or less early

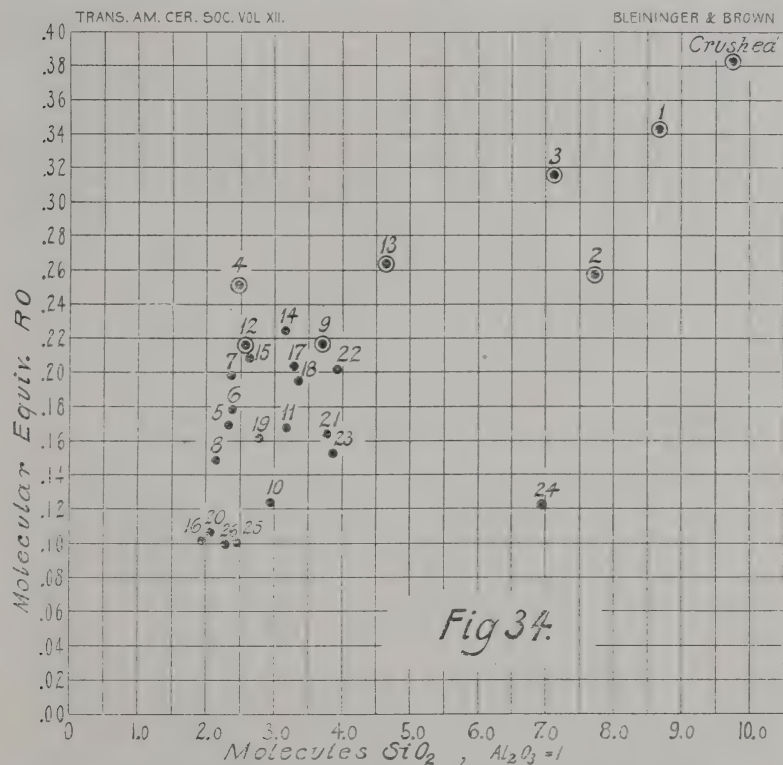
start in settling, and the rate at which this takes place increases with the temperature, till finally it becomes so rapid that it is impossible to keep the beam level. Failure then is merely a matter of minutes, and takes place very suddenly. In every case, therefore, softening precedes failure. With a third kind of material (of silicious composition, low in fluxes) the rise in height remains stationary for quite a while, followed by a long quiescent period. After the maximum temperature is reached a very slow and gradual settle takes place, which is quite small and decreases in rate as the temperature is kept constant. Such materials remain perfectly straight, and shrink but a small amount.

Undoubtedly some of the bricks tested would have been deformed badly on long time tests, which it was impossible to carry out under the conditions of the plant, but in several cases where the time of testing was extended considerably a kind of equilibrium seemed to be reached, after which no observable changes took place. It is very likely that in these cases solution of the more refractory portion of the brick took place, which stiffened up the bonding material.

Inspection of the failures shows plainly that the more refractory flint clay has not softened to the slightest extent. The grains have lost none of their original identity. They seemed to have slid upon each other, the bond clay acting analogously to a lubricant. From this it follows that, no matter how excellent the major constituent of the brick may be as to refractoriness, if the bond clay is deficient the load carrying power of the product is impaired. In other words, as far as this property is concerned, a fire brick is not any better than its weakest constituent.

It is observed that there is some rough relation between the softening temperature and the ability of the bricks to stand up under this test, but it is also seen that this is not true unqualifiedly. Test No. 16 is one of the decided exceptions. The failures not only show a softening

point below cone 30 but also a certain high content of fluxes, i. e., K_2O , Na_2O , MgO , CaO and FeO . On the other hand, while a brick may soften below cone 30, if its content of RO constituents is low it will resist the conditions of the load test without difficulty. In No. 24, we have an illustration of this kind, and many silica brick show similar results. Nevertheless, it seems quite clear that the load test is in a measure a determination of the refractoriness, in spite of the low temperature at which it is conducted.



No. 19 is not properly placed in this chart, as will be seen by reference to Table I.—Editor.

In Fig. 34 the failures due to the crushing of the bricks are plotted, and it is observed at once that the most

significant factor seems to be the RO content. It is not to be expected that a sharp division line exists between the area of failure and that of satisfactory load carrying ability, since in some cases the FeO, which constitutes part of the RO, may be present in the form of larger grains, in which condition it is not detrimental. The fact is again shown that neither the softening temperature nor the chemical analysis alone produces the information brought out by the load test. Given all three of these data, however, a very good presentation of the refractory resistance of a fire brick is obtained.

Examining the question from the chemical standpoint, and assuming that the fire brick body consists of a refractory constituent corresponding in composition to the kaolin formula, and of a more fusible cementing component, the following method might be pursued, taking for example one of the failures, say sample No. 4. The entire brick, on calculation from the average analysis, possesses the empirical formula: $0.019 \text{ Na}_2\text{O}$, $0.030 \text{ K}_2\text{O}$, 0.036 MgO , 0.026 CaO , 0.14 FeO , 0.054 TiO_2 , $1.00 \text{ Al}_2\text{O}_3$, 2.485 SiO_2 . Assuming that the alkalis are derived from feldspar, the alumina corresponding to $0.019 + 0.030$ alkali is 0.049 equivalent. Deducting this from 1 we obtain 0.951 equivalent of clay substance, which contains 1.902 equivalent of silica. Subtracting this from 2.485 leaves 0.583 silica. Beside 0.951 equivalent of pure clay base, this would leave the rest of the constituents to form the more fusible mixture: $0.019 \text{ Na}_2\text{O}$, $0.030 \text{ K}_2\text{O}$, 0.036 MgO , 0.026 CaO , 0.14 FeO , $0.049 \text{ Al}_2\text{O}_3$, 0.583 SiO_2 . Throwing this into another formula with RO equal to unity, we obtain: $\text{RO} \cdot 0.195 \text{ Al}_2\text{O}_3 \cdot 2.322 \text{ SiO}_2$. It is the amount and character (fusibility and viscosity) of this mixture which should govern the refractory behavior of the product under load conditions. From a rough estimate, it would seem that this composition is analogous to a quite fusible clay or acid slag, with comparatively low viscosity. The amount of this mixture might be calculated as follows:

0.049 · 37.35 =	1.83%	Al ₂ O ₃
0.583 · 54.58 =	12.83%	SiO ₂
	3.69%	FeO
2.485	0.54%	CaO
	0.53%	MgO
	1.02%	K ₂ O
	0.42%	Na ₂ O
	20.86%	

In this case, then, the fusible silicate mixture of the formula $RO \cdot 0.195 Al_2O_3 \cdot 2.322 SiO_2$ would constitute 20.86% of the total weight of the brick body, sufficient to cause it to behave as it did in the load test. In this theoretical speculation we must keep in mind that the effect is more marked, owing to the heterogeneous mixture of the assumed pure flint and impure bond clay. The more thoroughly the two materials are ground and blended together the better would the body behave in the load test, until finally the effect would be that corresponding to a single clay of the average composition, though even in this case it would remain a somewhat inferior material, owing to the high content of fluxes. The more impure the bond clay, therefore, the more complete and intimate should the mixture be.

An analysis of the relation between the initial, cold-crushing strength and the load behavior, shows no apparent connection, but the fact is brought out that low initial strength is a handicap. Bricks Nos. 4 and 11 are examples of this observation. While No. 4 would have failed irrespective of its cold-crushing strength, the failure was more complete on account of its weakness, and No. 11 in all probability would have shown a very much smaller condensation, in fact, would have stood the test.

The hardness of burning in a general way is a factor worthy of consideration. Although burning to a high temperature cannot, in the nature of the case, effect any fundamental change, and cannot convert a low grade material into a good one, our work has shown that well burnt bricks stand up better than soft burnt products. This is due, not only to the greater compactness of the body, but also to

the change in the composition of the bonding material where such is used. In other words, hard burning will cause the plastic clay, usually decidedly less refractory than the flint, to dissolve some of the fine part of the better material, thus increasing its own refractoriness and hence its resistance to load conditions. For instance, No. 26 would have shown up better if it had been burnt harder.

To what extent other changes, such as the formation of sillimanite at higher temperatures, would have a beneficial effect, it was not attempted to determine.

For the purpose of selecting materials for Government use, the tentative requirement was made that under the conditions of this test a 9" brick should not shorten more than one inch.

The results of the second series of tests in which the load is 50 pounds per square inch and the temperature $1350^{\circ}\text{C}.$, are very much like those obtained in the first series, but appear to bring out more the question of flow due to softening being somewhat less dependent upon the initial strength of the brick. It is intended to use the latter conditions in all further work.

REFRACTORIES MADE FROM ONE CLAY.

As to fire bricks made from a clay material which is sufficiently plastic so as to be used alone, it is clear that its ability to carry loads depends simply upon its composition. Some of the very best tests have been obtained from materials of this kind. This case is the simplest and needs no particular attention, since a clay will stand up or fail by virtue of its own quality. A pure clay of moderate plasticity would be the ideal material for the manufacture of fire brick. Since, however, such clays are usually not available, the question of judging them as to their composition deserves some attention from the standpoint of their load carrying capacity. From this point of view the most important consideration is that of the amount of fluxes.

At the high temperatures involved, the presence of

even a small amount of fluxes becomes a potent factor, and hence it is far better to select a clay higher in silica and low in fluxes than a clay possessing the silica-alumina ratio of koalin but higher in fluxes. The effect of silica in lowering the refractoriness of clays is commonly exaggerated as far as practical results are concerned, and it is usually not necessary to reject a clay on this account. However, high silica and high fluxes make a dangerous combination. From this it follows that a clay fairly high in fluxes, corresponding for instance to $0.22 \text{ RO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$, would be improved by the dilution with a silicious material low in fluxes, or even by the addition of a clean sandstone, the principal requirement being intimate blending and grinding.

In regard to the fluxes present in a clay, the state and size of grain of the iron is of importance, for it is evident that coarser grains of iron minerals will do no harm, though in the analysis they contribute their share towards raising the amount of fluxes. An effort should be made to determine the amount of such grains and to make the proper correction in the analysis.

The fluxes are an important factor in the ability of refractories to carry loads, inasmuch as they become active at low temperatures, as has been shown in the table of results, by forming easily fusible silicates. As the temperature rises increasing amounts of silica and alumina are dissolved, and it becomes, therefore, simply a matter of the amount of this fused matter and its viscosity, whether or not a given refractory will stand up at the temperature in question. As the temperature rises or the load is increased, a point is reached where the entire body becomes too viscous to retain its shape.

By grinding the clay as coarse as possible, conditions are improved, as in doing this the formation temperature of the fusible silicates is raised, since the process of solution is hindered, and by these means it may be possible to bring the product out of the danger zone. In time, however,

equilibrium conditions are approached closer and closer, so that finally the brick may fail under the same conditions under which they stood up at first.

BRICKS MADE FROM FLINT AND BOND CLAY.

In this case we are dealing with comparatively coarse grains of flint and fine grains of bond clay. These two materials are mixed and blended as far as the processes customary at the present time permit it. The bond clay breaks up more readily, and the plastic mass produced by it cements together the grains of flint clay and calcine. Assuming that the flint clay is of good quality, the load carrying capacity of the product depends upon the bond, as has been shown above. It is evident that if the flint is inferior the product suffers accordingly. These two materials may be considered from the standpoints of chemical composition, vitrification range and fineness of grain.

Flint Clay.

This material, the geological origin of which is still in dispute, is deficient in plasticity, although by very fine grinding it may become sufficiently plastic to be molded. It is of conchoidal fracture, often quite hard, and at its best approaches pure kaolin in composition, being often surprisingly low in fluxes. Its drying shrinkage is practically nil, but in burning it suffers as a rule a decided contraction in exterior volume. Its refractoriness, when pure, is very high. A brick made from flint clay (by fine and long continued grinding) is able to carry high loads. The vitrification range of flint clay has been well shown in the paper by Knote, in this volume. As far as refractoriness is concerned, it is good practice to grind it quite coarsely for reasons already indicated. The fact that occasionally it is in part calcined does not affect its refractory behavior, but simply corrects the shrinkage suffered in burning.

The physical characteristics of flint clay are not al-

ways a synonym for high refractory quality, as the writers have seen clays of this type which are decidedly inferior.

Plastic Bond Clays.

In these materials a good grade of plasticity is desirable, though this is less important where their refractoriness is high. In clays of greater fusibility high plasticity enables the manufacturer to cut down its amount to a minimum. In the selection of a bond clay it is evident that its vitrification range should be as long as possible, i. e., the temperature at which it becomes dense and non-absorbent should be as high as possible. The chemical composition and inherent mineral structure are thus most readily expressed by means of porosity-temperature curves, such as have been frequently described in these transactions, and which have been employed by Purdy in the study of Illinois fire clays. In making such tests, the time of burning should approach as much as possible the duration of the burns in actual practice. What has been said of the chemical composition of clays under the head of bricks made from one clay applies also here. The main consideration is that the amount of fluxes be as low as possible, irrespective of the silica or alumina content.

As to fineness of grain, it might be said that the grinding should not be carried any farther than is necessary to develop good plasticity.

Improvement of Bond Clay.

If a flint-bond-clay mixture should prove unsatisfactory as regards its ability to carry loads, the first step would be to cut down the amount of plastic clay if possible. If this should not be possible or beneficial, the plastic material could be improved by grinding it intimately with a portion of the flint clay to such a degree of fineness as would insure thorough incorporation. This could be done by dry or, preferably, wet grinding. In the latter case it might be possible to pug the additional, coarser flint clay into the slip, which naturally would be maintained as thick

as possible. The finely ground flint would not remain inert but would be sure to possess some plasticity.

Another alternative would, of course, be the substitution of another clay for the unsatisfactory plastic bond. Since not infrequently silicious clays are at hand, this might prove feasible, even though the amount of bonding material would have to be increased. Where the flint clay is becoming scarce, it might be possible to find some soft sand rock which could be ground into the plastic bond clay, and which would thus improve its behavior under load conditions.

By some such means as have been indicated here, it would not seem a difficult matter in most cases to manufacture products fulfilling all reasonable conditions as to crushing strength at the usual furnace temperatures. In addition, by paying attention to the sizing of the ground clays, so as to produce as dense a structure as possible, by the use of less water or by adopting dry pressing, the load carrying ability of the brick is increased. Likewise, burning at a higher temperature assists in bringing about the same result. Experiments carried on by the writers have shown that harder burning has increased the strength of fire bricks appreciably.

CONCLUSIONS.

1. The softening temperature of fire brick specimens is not a safe criterion of the resistance to load conditions at the average furnace temperatures. The same is true of the chemical analysis. By means of both the so-called melting point and the chemical analysis, the load behavior may be approximated. This cannot take the place, however, of a direct test. The RO constituents (including the iron as FeO) should be as low as possible, and for best results should not exceed 0.22 equivalent. The content of fluxes is more important than the silica content.

2. The test described appears to fulfill the requirements of a load test for fire brick, since the results are

consistent and admit of close checking. It is recommended that the load be fifty pounds per square inch and the temperature 1350°C . A No. 1 brick should show no marked deformation and should not be shortened more than one inch, for the standard nine inch length. The test estimates in a measure the refractoriness.

3. From the results of this test it appears that the amount and fusibility of the least refractory clay constituent govern the behavior of the brick under load. Improvement will result by grinding the less refractory clay intimately with flint clay or even silicious materials, low in flux, improving the density, and by harder burning.

DISCUSSION.

Mr. Parker: I certainly take a great interest in the paper of Professor Bleininger, as I at one time undertook to make investigations of this very kind, but all were at higher temperatures and with smaller loads. We were having trouble which was attributed to shrinkage, and I was soon satisfied that it was from some other cause. I would like to see these experiments carried a little further and at higher temperatures, which would result in data of very great value.

Mr. Hipp: I would like to mention that recently we have done some work along this line, although our appliances were nothing like Professor Bleininger's. I would like to ask whether Professor Bleininger thinks that the viscosity temperature, the temperature at which the bricks become viscous, has any direct bearing on the strength that the bricks might withstand?

Mr. Bleininger: It appears that the viscosity of the brick at lower temperatures is the principal cause of failure.

Mr. Hipp: Do you think burning the brick harder in manufacture would increase the strength?

Mr. Bleininger: I think so. It would tend to hold it up at higher temperatures.

Mr. Ramsay: As I understand Mr. Bleininger's remarks, the higher the crushing strength the better it will stand the heat. Take for illustration a fire clay, grind it very fine, and burn it in a kiln at a very high temperature. Will that brick stand more hot crushing strain than the brick that is not ground fine?

Mr. Bleininger: Given two bricks of equal refractoriness, the one with the greater initial compressive strength will have somewhat of an advantage. Fine grinding does not necessarily mean a decrease in porosity, but rather the reverse. The pores are smaller but the porosity is greater.

Mr. Ramsay: With coarse ground material the distance between the particles is greater than with fine ground. Under the heat conditions it takes longer to come in contact as they are further apart.

Mr. Bleininger: We must remember that where flint clay is used in making fire bricks we are dealing with two materials, the flint clay and the bond clay. The latter is, as a rule, very much finer than the former. By a suitable combination of coarse and medium fine flint and fine bond clay, the greatest initial strength is produced. It is evident that the more porous a brick is the less solid material it has to sustain the load. The coarser the clay is the longer it will resist the heat effect, but we must remember that in furnaces operated continuously we have a long time effect. It is obvious, however, that the bond clay cannot be coarse since this would defeat the purpose for which it is used. The weak point, therefore, is with the bond. If the latter is of high grade the brick will stand under the load, if not it will fail. But I have shown clearly how the product may be improved if the bond should not be of first quality.

Mr. Ramsay: I wish to bring out, if possible, what relation the cold crushing strain will have to the hot crushing strain?

Mr. Bleininger: There is very little relation. If a brick is physically weak under ordinary burning condi-

tions and is defective in composition, you can improve that material somewhat by making it stronger, but it will not be a fundamental remedy.

Mr. Ramsay: In other words, if one brick is soft burned and one is hard burned, the hard brick will stand the greater heat?

Mr. Bleininger: Hard burnt fire bricks seem to stand up better than soft burnt.

Mr. Hamilton: In Professor Bleininger's investigation he has found that the less refractory brick stood the greater test when cold?

Mr. Bleininger: The cold strength, as I have said before, has direct relation to the strength in the furnace. We have tested highly refractory materials that showed a good strength when cold.

Mr. Hamilton: And while the photographs do not show up as badly in the hot tests, that is the less refractory brick. Now, we make a brick that we think is very highly refractory. That would be a rough grained brick containing a binder of 20% of plastic clay. That brick would be very porous and I take it that the hot strain would be very low, but at the same time that brick would stand a greater heat than 1300 degrees where it did not come in contact with a load. A brick containing flint and bonded with 30% plastic clay would not show up as well, but would be a satisfactory brick for the roof of a furnace. The thing that I would like to find out is, would it be better to make a fine ground brick than one coarse ground? Your experiment has not shown that.

Mr. Bleininger: I want to say that I think I have been misunderstood. By grinding the whole brick mixture finer you of course improve the standing up quality of an inferior bond clay. But it is not necessary to do this. If for instance you were to grind the bond clay with some of the flint very fine, and then mixed this combination with your coarser ground flint, as usual, you would obtain the best result. I say distinctly that I am speaking of brick,

suitable for carrying loads at furnace temperatures, and realize fully that a brick may stand up at a high temperature if no load is imposed, while it would fail in this test. There is a very rough connection between the ability of a brick to stand up under this test and its so-called refractoriness. A brick softening below cone 30 would not stand much of a chance in the load test.

Mr. Parker: I think if Professor Bleininger goes a little farther in his experiments he will find that the results do not agree at higher temperatures. Beyond 1300 degrees C. they would not agree at all. At least that is my experience.

Mr. Bleininger: We selected the temperature because it is a very common furnace temperature.

Mr. Parker: I was compelled to go higher, and I found that one kind of clay standing unusually high temperatures was not as good a load carrier at a minimum temperature of 2400° to 2500° F. as a less refractory clay.

Mr. Hamilton: The point is, I do not think we can get a highly refractory brick sample and at the same time a brick that will stand up well under load conditions, because you cannot introduce the bond and hold up with the temperature.

Mr. Yates: At higher temperatures in the making of fire brick you take all the shrinkage out of your clay.

Mr. Hipp: I would like to say concerning the percentage of plastic clay used, that we made some tests recently, trying different amounts, and found that two bricks of practically the same refractoriness, one containing 30% of bonding clay and the other 50%, showed considerable difference as to their ability for withstanding the strain imposed. I would like to ask Professor Bleininger whether in testing two fire bricks, each containing a different amount of plastic clay but the porosity about the same in each brick, the crushing strength would vary to any great degree?

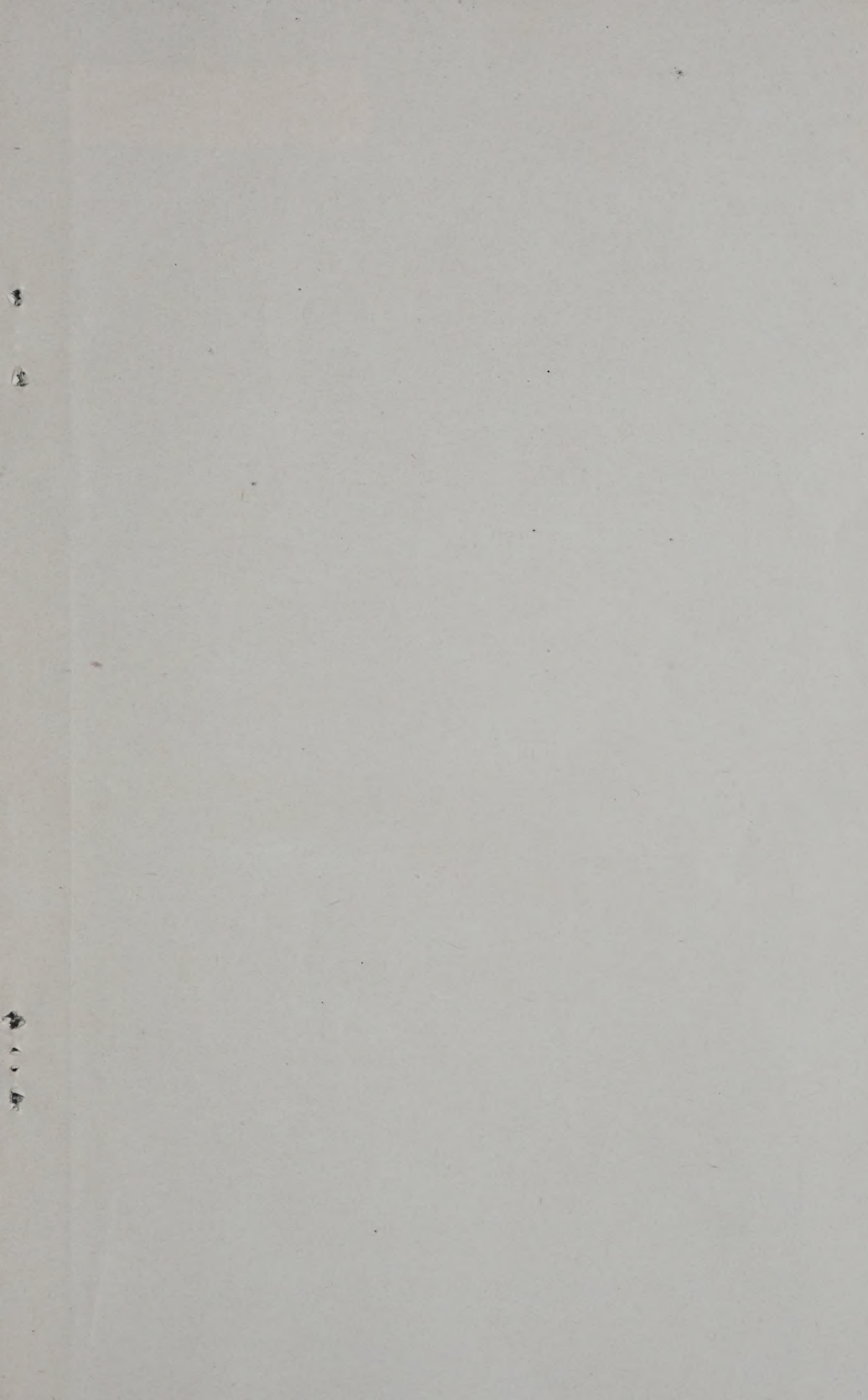
Mr. Bleininger: I cannot answer this question satisfactorily.

Mr. Ramsay: I think you have stopped too soon. We know your position in this line of work, and our customers would be apt to take your opinion rather than ours, and I think sometimes your conclusions are erroneous. I think that sometimes the clay used in bond has some effect upon the brick.

Mr. Bleininger: Of course, we stand back of our results, as they have been made with care, and I cannot retract one word of what I have said. When Mr. Ramsay speaks of the effect of the bond clay, I wish to call attention to the fact that this is the very thing which we have emphasized.

Mr. Parker: I would like to say that at higher temperatures Mr. Bleininger will find different results. At his temperature they agree with my experiments. You will find at higher temperatures that an ordinary fire clay promising good results as a load carrier, though still far from its fluxing point, may lose its efficiency in this respect, while the more refractory clay will prove more efficient with a moderate load to a temperature much nearer its fusion point.







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